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Editor: From this issue on, this special column will systematically introduce 7 papers devoted to the "S-band Telemetry Channel System", which was developed by Institute 704 of the Aerospace Industry Headquarters after many years of arduous effort. The following two papers published in this issue describe the overall condition of the system and its receiver, while the next few issues will introduce its subsystems one by one.

Universal S-Band Receiving Channel

Xu Lianbin and Xu Furen

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Abstract: The S-band receiving channel introduced in this paper is a universal telemetry tracking channel. The channel can carry antenna feed, radio frequency, frequency domain synthesis, receiver and upper and lower frequency conversion. The S-band allows an easy connection with telemetry stations overseas and its dot frequency and bandwidth are designed in conformity to international standards. Therefore, it has high adaptability to a diversity of telemetry systems, either to telemetry or, while spread, to angular tracking and outer space surveys.

Key words: S-band, receiving channel, tracking

1. Introduction

The S-band receiving channel system is a new generation universal receiving channel system developed on the basis of foreign advanced techniques, bravely absorbing and applying new techniques, new devices and new technologies at home and abroad. This system conforms to the present condition of our country.

In China, for a long time in the past, non-international universal bands, mainly the 400MHz band, had been used in telemetry, which, in most cases, operated manually or through program control, and even self-tracking systems could track only carrier wave signals. The maximum code rate capacity of the channel was only 320kbps, and there were only a few VHF bands and C-bands which were used in phase modulation system with a fairly low code rate capacity.

Since 1987, to make the receiving channel standard, our institute was the first in our country to develop the S-band receiving channel in agreement with the international standard. In the process, an FM carrier wave continuous spectrum non-carrier wave automatic tracking was realized for the first time by using a single-channel, single-pulse tracking technique which was then already widely applied in telemetry in some foreign countries. In signal transmission, conversion and processing, a symmetric diversity two-mold phase-lock loop technique--the newest technique in the world--was utilized to realize pre-detection maximum ratio diversity synthesis. This technique can avoid data deterioration caused by phase discontinuity due to primary and secondary diversity synthesis and overcome the effect of dynamic fading, resulting in diversity gain improvement. The wide band, multi-dot frequency and code conversion rate channel, which include telemetry and GPS outer space survey frequencies, provided a signal dynamic scope as high as 100dB and was compatible with GPS outer space survey requirements. In addition, the threshold spread FM demodulation technique was employed to reduce the demodulated threshold values. The overall system enjoyed rather high capabilities of automatic monitoring and control.

2. Basic Concept of System Design

The S-band receiving channel system is a new generation telemetry receiving channel intended for use in test ranges of China. The major design concept of the system is as follows:

(1) Facing the 21st century, to make use of the international universal S-band in a unified way and to fit the design into IRIG standard and GJB standard;

(2) Based on the actual conditions in our country, to keep track of and absorb as many of the most recent foreign technical achievements as possible, and develop a receiving channel system with Chinese characteristics;

(3) Design a universal receiving channel, suitable for different models of modulation systems, various telemetry systems with different code rates and applicable to tracking with and without carrier waves;

(4) Based on 2Mbps, spread to high-code-rate telemetry needed for new models;

(5) Design an extensible receiving channel, available for telemetry, goniometry and compatible with GPS outer space surveys;

(6) Under the premise of advanced technical indexes, pay spacial attention to reliable design, standard design and quality control so that the reliability of the new generation telemetry equipment developed in our country can jump to a new level.

3. Composition and Properties of the System

The S-band receiving channel system consists of the following subsystems as shown in Fig. 1.

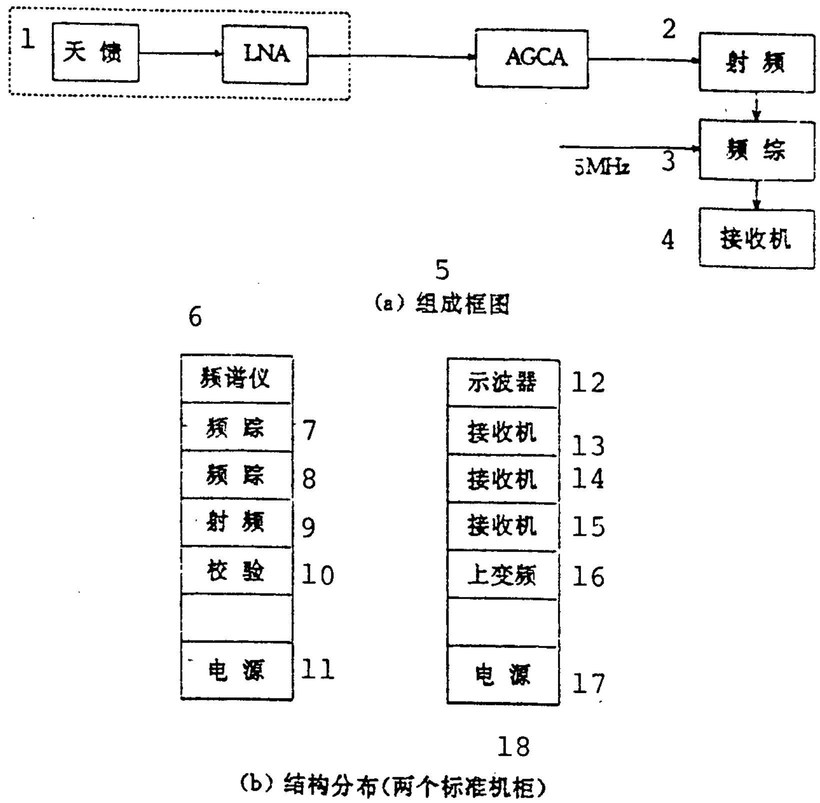

Fig. 1 Block Diagram of Composition of Receiving Channel

Key:
(1) Antenna feed
(2) Radio frequency
(3) Frequency domain synthesis
(4) Receiver
(5) (a) Block diagram of composition
(6) Frequency spectrograph
(7) Frequency domain synthesis
(8) Frequency domain synthesis
(9) Radio frequency
(10) Checking
(11) Power supply
(12) Oscillograph
(13) Receiver
(14) Receiver
(15) Receiver
(16) Upper frequency conversion
(17) Power supply
(18) (b) Structural arrangement (two standard equipment cabinets)

They are the antenna feed subsystem, radio frequency channel subsystem, intermediate frequency domain synthesis combination, TMR diversity receiver and upper frequency conversion combination.

The major technical properties of the system are:

(1) Application of international universal S-band with 100 dot frequency options;

(2) The antenna and feed source are dismountable, suitable for a mobile telemetry tracking station, which is the largest mobile telemetry station in China;

(3) The main antenna is equipped with a wide beam guidance antenna array, convenient for target acquisition;

(4) The main antenna and guidance antenna adopt a single-channel and single-pulse tracking system to greatly simplify the equipment and increase its stability and reliability;

(5) The large and small antenna feed source networks adopt the microband technique and can realize feed source miniaturization;

(6) The receiving channel is a channel of comprehensive usage, i.e. it transmits telemetry information via frequency and transmits angular tracking information via amplitude. Therefore, it does not matter whether or not the target tracking signal has or does not have a carrier wave. This technique was the first to be developed and utilized in China;

(7) This system incorporates high sensitivity reception and intensive signal reception and can enlarge the dynamic scope, resulting in extending the scope of the arrangement of receiving sites;

(8) This system can receive two high code rate telemetry data flow signals simultaneously and possesses spreading capabilities;

(9) In receiving telemetry signals, the system has the capability of receiving GPS outer space survey signals at the

same time, so that it can extend to a telemetry and outer space survey integration system;

(10) All the channels of the system adopt a polarized diversity reception technique. Thus, it can improve the signal-noise ratio, eliminate the effect of signal polarization fading and increase the reliability in signal reception;

(11) The system adopts a FM threshold spread technique to reduce the FM demodulation threshold S/N;

(12) The receiving channel can automatically and quickly switch the receiving bandwidth and operation conditions in response to the on-missile telemetry code conversion rate instructions;

(13) For the first time in our country, the system can receive telemetering data of two data flows: pre-detection recording and replay;

(14) This system can perform self-checking of its functions by using calibration radio frequency and intermediate frequency system-checking equipment.

4. Analysis and Computation of Major System Technical Indexes

Known conditions:

Telemetry transmitter power: P_t=7W→8.5dB

Transmitting antenna gain: G_t=-8dB

Receiving antenna gain: $G_{r\ main}$=38.5dB

$G_{r\ guidance}$=22dB

Transmitting antenna feeder loss: L_t=1dB

Transmitting antenna feed source loss: $L_{r\ main}$=1.2dB

$L_{r\ guidance}$=2.5dB

Polarization loss: L_P=1dB

Atmospheric loss: L_A=1dB

Safety margin: S_F=6dB

Channel equation:

Channel equation computed based on dB number is

$$P_t+G_t+G_r=S_0+L_r+L_t+L_r+L_P+L_A+L_F \quad (1)$$

where S_0 is receiving threshold level; L_R is path loss

By substituting the known figures into the equation, the following is derived:

Main antenna: $8.5-8+38.5=S_0+L_R+1+1.2+1+1+6$

$$L_{R\ main}=28.7-S_0 \quad (2)$$

Guidance antenna: $8.5-8+22=S_0+L_R+1+2.5+1+1+6$

$$L_{R\ guidance}=11.2-S_0 \quad (3)$$

4.1 System noise Spectrum Density

The system noise temperature at the first-level LNA input end is computed as

$$T_{sr}=T_a/L_F+(1-1/L_F)T_0+T_F \quad (4)$$

where T_a=noise temperature of antenna in cold space=65K at an elevation of 5°

T_0=room temperature selected as 293K

T_F=system noise temperature at the first-level LNA input end, computed by radio frequency system

$$=T_1+T_U/G_1+T_2/G_1G_2+T_0/G_1G_2G_{L1}+T_H/G_1G_2GL1G_{L2}$$

The definitions of the parameters in the equation are shown in Fig. 2.

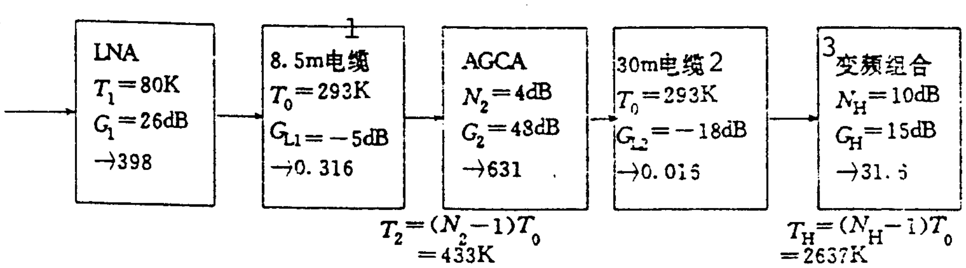

Fig. 2 Noise Temperature Distribution

Key: (1) Cable; (2) Cable; (3) Frequency conversion combination

By substituting the known figures in Fig. 2 in the above equation, the following is derived:

$$T_F=80+293/398+423/125.8+293/79359.6+2637/1269.8$$
$$=80+0.74+2.36+0.004+2.08$$
$$=85.18K$$

Taking equipment tolerance and imperfect matching into account, select T_F=110K

$L_{F\ main}$=1.2dB;

$L_{F\ guidance}$=2.5dB

Main antenna and channel feed source loss includes:

(1) Polarized bridge loss L_1=0.3dB

(2) Loss of 12dB directional coupler of single-channel converter L_2=0.3dB

(3) Semi-steel connection cable loss L_3=0.3dB

(4) Socket and mismatching loss L_4=0.3dB

Total loss $L_{F\ main}$=0.3+0.3+0.3+0.3=1.2dB→1.32

The guidance antenna and channel feed source loss includes:

(1) Polarized bridge loss L_1=0.3dB

(2) Three-ring sum differentiator loss L_2=3x0.3=0.9dB

(3) Loss of 9dB directional converter of single-channel converter L_3=0.6dB

(4) Bridge to sum differentiator 0.7m cable loss L_4=0.5dB

(5) Other losses L_5=0.3dB

Total loss $L_{F\ guidance}$=0.3+0.9+0.6+0.5+0.3=2.6dB

Taking measures in design technology to control $L_{F\ guidance}$ 2.5dB→1.78.

The total noise temperature at the first-level LNA input end, computed by the system, is:

Main antenna system: $T_W=65/1.32+(1-1/1.32)293+110$

$=49.24+71.03+110$

$=230.0K \rightarrow 23.6dB$

Guidance antenna system: $T_W=65/1.78+(1-1/1.78)293+110$

$=36.52+128.4+110$

$=275K \rightarrow 24.4dB$

The system equivalent noise spectrum density is computed based on dB:

Main antenna system $N_{0\ main}=K+T_W$

$=-228.6+23.6=-205.0dBW/Hz$

Guidance antenna system $N_{0\ guidance}=-228.6+24.4$

$=204.2dBW/Hz$

where k=-228.6dB is Boltzmann constant.

4.2 Receiving Threshold Level

Telemetry Threshold Level

Under the condition that 10^{-4} error code rate is ensured, telemetry PCM video frequency requires $(S/N)_v=13dB$, while the optimal video bandwidth $B_v=0.7f_b$.

(1) When $f_b=2Mbps$, $B_v=0.7f_b=1.4MHz \rightarrow 61.46dB$

In PCM-FM modulation system, $m_f=0.7$

The ideal intermediate frequency bandwidth $B_{IF}=1.2f_b=2.4MHz$.

Considering the unstable frequency factors, the standard bandwidth is given as $B_{IF}=3.3MHz \rightarrow 65.19dB$,

then the intermediate frequency threshold signal-noise ratio can be computed based on dB as

$$(S/N)_{IF}=13-(B_{IF}-B_v)$$
$$=13-(65.19-61.46)=13-3.73=9.27dB$$

Considering the loss of non-ideal intermediate frequency filter matching, given

$$(S/N)_{IF}=10dB$$

then at 2Mpbs, 10^{-4} error code threshold level is:

Main antenna system: $S_{0\ main}=N_{0\ main}+B_{IF}+(S/N)_{IF}$

$$=-205+65.19+10=-129.81dBW$$

Guidance antenna system: $S_{0\ guidance}=N_{0\ guidance}+B_{IF}+(S/N)_{IF}$

$$=-204.2+65.19+10$$

$$=-129.01dBW$$

(2) When code rate f_b=20kpbs, m_f=13, f=130kHz

$$B_v=0.7f_b=14kHz\rightarrow 41.2dB$$

$(S/N)_v)$=13dB is PCM error code threshold

The ideal $B_{IF}=(2+m_f)f_b=(2+13)20=300kHz\rightarrow 54.8dB$

As the FM frequency discriminator has a certain threshold effect, the threshold spread technique is used in the system. When the front-to-intermediate frequency signal-noise ratio of the frequency discriminator $(S/N)_{IF}$=6dB, it outputs $(S/N)_v)$>13dB. Therefore, at f_b=2kpbs, the telemetry threshold level is:

Main antenna system: $S_{0\ main}=N_{0\ main}+B_{IF}+(S/N)_{IF}$

$$=-205.0+54.8+6$$

$$=-144.2dBW$$

Guidance antenna system: $S_{0\ guidance}=N_{0\ guidance}+B_{IF}+(S/N)_{IF}$

$$=-204.29+54.8+6$$

$$=-143.4dBW$$

(3) When f_b=320kpbs, m_f=0.7, PACM-FM system

$B_v=0.7f_b=224kHz$, given B_v=300kHz

$B_{IF}=1.2f_b=1.2x320=384kHz$

Considering unstable factors of frequency, given $B_{IF}=750kHz\rightarrow 58.8dB$,

given threshold $(S/N)_{IF}$=12dB, then based on dB, the receiving threshold level is computed as:

Main antenna system: $S_{0\ main}=N_{0\ main}+B_{IF}+(S/N)_{IF}$

$=-205.0+58.8+12$

$=-134.2dBW$

Guidance antenna system: $S_{0\ guidance}=N_{0\ guidance}+B_{IF}+(S/N)_{IF}$

$=-204.2+58.8+12$

$=-133.4dBW$

4.3 Tracking Threshold Level

The single-channel and single-pulse thermal noise angular error equation is:

$$\delta_t = [(d_c/2)(N_0 B_N/S)(1 + N_0 B_{IF}]^{1/2}/K_0 \qquad (5)$$

where $K_{0\ main}=56.2$, $V/(°)$ is main antenna goniometric error slope; the guidance antenna goniometric error slope is $K_{0\ guidance}$ $=11.94V/(°)$, d_c is coupling degree of the single-channel converter, which is $S_{c\ main}=12dB\rightarrow15.85$ for the main antenna and $d_{c\ guidance}=9dB\rightarrow7.94$ for the guidance antenna,

$B_N=1.5Hz$ is the servo ring circuit bandwidth.

By converting Eq. (5), the following **is derived:**

$$(S/N)_0 = 2B_{IF}/[1 + 8B_{IF}K_0^2\delta_t^2/B_N d_c)^{1/2} - 1] \qquad (6)$$

Based on the angular error analysis, the threshold level thermal noise error is generally selected 1/10 of the total goniometric error. For the main antenna tracking system, σ_{total} $\sigma_{total\ main}=0.1°$.

$\sigma_{t\ main}=0.1\sigma_{total\ main}=0.1x0.1°=0.01°\rightarrow0.173x10^{-3}$

The goniometric error for the guidance antenna system, $\sigma_{total\ guidance}=0.5°$

$\sigma_{t\ guidance}=0.1\sigma_{total\ guidance}=0.1x0.5°=0.05\rightarrow0.87x10^{-3}$

When B_{IF}=3.3MHz

(1) Main antenna tracking system

$$(S/N_0)=2x3.3x10^6\div\{[1+8x3.3x10^6x56.2^2x(0.175x10^{-3})^2 \div(1.5x15.85)]^{1/2}-1\}$$
$$=6.6x10^6/(9.61-1)$$
$$=7.7x10^5\rightarrow58.85dB$$

The main antenna tracking threshold level is computed based on dB

$$S_{0\ main\ tracking}=N_0+S/N_0=-205.0+58.85=-146.15dBW$$

(2) Guidance antenna tracking system

By simplifying Eq. (6)

$$S/N_0=2B_{IF}/[2K_0\sigma_t(2B_{IF}/B_Nd_c)^{1/2}-1] \quad (7)$$

By substituting related data,

$$d_c=9dB\rightarrow7.94,\ \sigma_t=0.873x10^{-3},\ K_0=11.94V/(°)$$
$$S/N_0=2x3.3x10^6\div\{[2x11.94x0.873x10^{-3}(2x3.3x10^6/1.5x7.94)^{1/2}]-1\}$$
$$=6.6x10^6/(20.78x0.554^{1/2}-1)$$
$$=4.56x10^6\rightarrow56.6dB$$

The guidance antenna tracking threshold level is computed based on dB

$$S_{0\ guidance\ tracking}=N_0+S/N_0=-204.2+56.6=-147.6dBW$$

4.4 Acting Distance Estimation

The main antenna and guidance antenna acting distance can be computed from the channel equation based on dB

$$L_{R\ main}=28.7-S_0 \quad (2)$$
$$L_{R\ guidance}=11.2-S_0 \quad (3)$$

The attenuation constant of S-band signal in free space is

$$K_L = 99.4 \text{dB/km}$$

then the acting distance is

$$R = \lg^{-1}[(L_R - K_L)/20] = \lg^{-1}[(L_R - 99.4)/20] \text{(km)} \quad (8)$$

By substituting the above-mentioned state data in Eqs. (2), (3) and (8), the computation results are listed in the following table:

1 信道	2 接收天线 3 数据 4 项目	f_b (kbps)	B_{IF} (MHz)	S_0 (dBW)	L_R (dB)	R (km)
5 遥测	主天线 6	2000	3.3	−129.81	158.51	902.61
		20	0.3	−144.2	172.9	4731.51
		320	0.75	−134.2	162.9	1496.2
	引导天线 7	2000	3.3	−129.01	140.21	109.8
		20	0.3	−143.4	154.6	575.4
		320	0.75	−133.4	144.6	182
跟踪 8	主天线 9	2000	3.3	−146.15	174.85	5922.43
	引导天线 10	2000	3.3	−147.6	158.8	933.3

Key:
(1) Channel
(2) Receiving antenna
(3) Data
(4) Terms
(5) Telemetry
(6) Main antenna
(7) Guidance antenna
(8) Tracking
(9) Main antenna
(10) Guidance antenna

5. Brief Description of System Working Principle

The block diagram of system composition is shown in Fig. 1a.

When PCM-FM telemetry signal is radiated from aircraft, the wide-beam guidance antenna, acquiring the signal and tracking the target, guides the main antenna to aim at the target and starts self-tracking. The main antenna and guidance antenna respectively change the signal, through the polarization bridge, to two signals: lefthand and righthand signals. These two path signals respectively form, in their beam formation networks, three-channel and single-pulse signals, and convert, through the single-channel and single-pulse converter, the telemetry signal and the tracking angular error signal into a composite signal, whose intermediate frequency modification (FM) transmits telemetry information, while its amplitude modification (AM) transmits tracking angular error information; the lefthand and righthand paths receive and transmit similar information to the diversity receiver.

The main antenna used is the focal feed parabolic antenna, while the guidance antenna is the quaternary backfire antenna array. The two antennas have parallel axial lines and share the same antenna mount, taking advantage of their beam width difference and gain difference to ensure a stable tracking within the main beam.

The lefthand and righthand 4-path composite signal transmitted from the feed source of the main and auxiliary antennas is amplified through the 4-path LNA installed in the feed source and delivered, through the radio frequency cable and the antenna mount, to the 4-path AGCA installed at the bottom of the antenna mount for amplification. AGCA is an automatic gain control amplifier, which is designed to prevent the channel from being blocked by extremely intensive signals when the receiving station is too close to the target, as well as to stop the signal from missing while operating in a non-linear zone.

The 4-path signal, once amplified by AGCA, is fed through a 30m radio frequency cable to the frequency conversion combination in the electronic equipment vehicle for amplification and first frequency conversion. The first local oscillation 2000MHz is formulated by frequency multiplication of the high-stability and low-phase noise 5MHz frequency marker so as to ensure its low phase noise index. The first intermediate frequency is a 250.5±50MHz wideband signal which enters the intermediate frequency domain synthesis combination for amplification and is then converted, through second lower frequency conversion, to a 16MHz main intermediate frequency. The step generated by the 5MHz marker as reference is 100 1MHz dot frequencies. The 410.5MHz±50MHz frequency synthesizer serves as the second local oscillation to ensure that the output main intermediate frequency still remains at 16MHz even if the 100 dotting frequencies vary within the range between 2200.5 and 2300.5 MHz.

The system is equipped with three sets of independent frequency synthesizers, which can make three sets of receivers independently receive the dot frequency signals from their respective radio frequency channels and separate them out of the common channel.

The system is compatible with GPS outer space surveys and they share the S-band telemetry channel and can easily separate the orthogonal lefthand and righthand path GPS signals, which, together with the 5MHz marker, are delivered to the GPS demodulation processing system, Thus, the two systems can be correlated in both frequency and phase.

The lefthand and righthand path signals from the main antenna respectively separate, in the intermediate frequency synthesizer, two 160MHz intermediate dot frequency signals which enter two independent TMR diversity receivers. The dot frequencies of the lefthand and righthand signals received from the guidance antenna can be modulated, according to the guidance needs, to either one of the two dot frequencies received by the main antenna, with their lefthand and righthand signals entering an independent TMR diversity receiver.

The guidance receiver and two main antenna receivers use a unified TMR diversity receiver for the convenience of interchange and maintenance. The sub-signal receiver adopts a new symmetric diversity reception technique to reduce the effect of signal fading on reception quality. To meet the requirements of the telemetry system in changing the code rate and modulation degree during in-flight measurement, an automatic switching program is set in the receiver to quickly change its bandwidth and time constant in response to the instructions of changing the telemetry code rate, received in accordance with the preset program.

Following three frequency conversions, the third intermediate frequency that the receiver uses is 20MHz, where the lefthand and righthand signals form a synthesized signal through symmetric diversity. The diversity synthesizer consists of a module ring and a differential module ring. The summing module ring is designed to eliminate the frequency difference between the lefthand and righthand signals, while the differential module ring--to remove the phase difference between the two signals. Thus, the same phases of the two signals can be added in the synthesizer so as to improve their signal-noise ratio. Once synthesized, the signal is divided into three paths. The first path, after frequency discrimination, outputs PCM(PACM) group signal and is further divided into two subpaths: one of them is delivered to the telemetry subsystem for demodulation processing, while the other is sent to YJ2-14 for post-detection recording. The second path becomes, following the lower frequency conversion, its band signal and is delivered to YJ2-14 for pre-detection recording. The third path is sent to the angular error demodulator for extraction and separation of the azimuth and pitch error signals and then to the tracking servo subsystem for controlling the antenna and accomplishing the automatic target tracking.

The rear-to-intermediate frequency of the synthesized signal is equipped with 4 intermediate frequency bandwidths and accordingly, following frequency discrimination, there are 4 video frequency bandwidths which are allocated based on different code rates and requirements.

The entire TMR diversity reception is managed by computer, which can set the overall status and can communicate with other computers outside the system and also, it can perform remote setup of the 100 dotting frequencies of the intermediate frequency synthesizer.

6. Major Technical Indexes of System

Main antenna gain: 39dB
Guidance antenna gain: 22dB
Main antenna summing beam width: 1.6°
Guidance antenna beam width: 10°
Zero depth of main and guidance antennas: ≤-30dB
LNA noise temperature: 80K
First intermediate frequency: 250.5±50MHz
Main intermediate frequency: 160MHz
Third intermediate frequency: 20MHz
Intermediate frequency bandwidth(MHz): 3.3, 2.4, 0.75, 0.3
Video frequency bandwidth(MHz): 1.5, 1.0, 0.3, 0.25
Dotting frequency: 100; step 1MHz
AGC scope: 100dB
AFC scope: ±250kHz
Angular error reference signal frequency: 1kHz
Angular error output slope: main antenna: ±5V(°);

guidance antenna: ±1V(°); all maximum output--5V

7. Conclusions

The S-band receiving channel system, with its remarkably sophisticated strategic technical indexes, is a big step ahead of the conventional telemetry channel. Owing to its widely applicable flashing capabilities, this system is compatible with a variety of telemetry self-tracking systems, suitable for aerospace and aviation telemetry or usable for civilian-oriented telemetry systems as reference. For a certain period of time in the future, it will be the fundamental telemetry reception system in our country. So far, this system has been matched with 7 telemetry model systems, and dozens of such receivers have been put in use for customers. It won the second science and technology progress award in the Aerospace Industry Headquarters.

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This paper was received on March 5, 1995.